Table I.—All areas in cm.$^2 \times 10^{-15}$.

Gas.	$\bar{S}$.	$\bar{B}/\bar{S}$.
Carbon dioxide	0·870	1·03
Nitrous oxide	0·867	1·03
$\bar{B} = 0·895$		

In both cases the ratio $\bar{B}/\bar{S}$ is seen to differ by only 3 per cent. from unity. We can, therefore, conclude that not only have the molecules CO_2 and N_2O the same molecular dimensions, but that their behaviour is, within the limits of experimental error, consistent with the assumption that in both cases the dimensions are those of three neon atoms in line with contiguous outer electron shells.

Experiments on Electron Emission from Hot Bodies.

By Sih Ling Ting, M.Sc., Birmingham.

(*Communicated, with a Preface, by* Prof. O. W. Richardson, F.R.S.)

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PREFACE.

The first measurements* of the kinetic energy of the electrons emitted from hot bodies were made by myself, partly in collaboration with Dr. F. C. Brown, in 1907–1909. The completed experiments were practically confined to platinum as a source of emission, largely on account of technical difficulties experienced with other materials. These experiments showed that the velocity distribution among the emitted electrons was in close agreement with Maxwell's law of distribution for a gas, of molecular weight equal to that of the electrons, in thermal equilibrium at the temperature of the source. This applies both to the component of velocity normal to the emitting surface and to that in a perpendicular direction. In the simple unidimensional case, where the cathode and anode form parallel planes of indefinite extent, the current, i, which flows against a retarding potential, V, depends only on the normal velocity component, and with Maxwell's distribution is given by

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* 'Phil. Mag.,' vol. 16, pp. 353, 890 (1908); vol. 18, p. 681 (1909).

$$i = i_0 \exp.(-\alpha V), \tag{1}$$

where $\alpha = e/kT$, e being the electronic charge, k the Boltzmann constant, T the absolute temperature, and i_0 the current when $V = 0$. The inverse of the factor α is in fact a measure of the energy with which the electrons are ejected from the surface.

The experiments showed that, with platinum under a very considerable variety of conditions, the exponential equation was obeyed with considerable accuracy. The average of eight determinations of k/e by this method agreed with the theoretical value to within a fraction of 1 per cent.,* although the individual determinations differed from the average by almost 20 per cent. These variations were undoubtedly large, and in excess of expectation from any obvious source of experimental error. At the same time, these experiments were subject to a number of defects such as might arise from (1) inequalities in the temperature of the source, (2) unsatisfactory methods of determining these temperatures, (3) the difficulty of realising a truly plane surface of hot metal, and (4) the presence of the electric and magnetic fields caused by the electric currents used in heating the source. In view of these and other known sources of uncertainty, the foregoing experiments, as a whole, were taken to indicate that the electrons emitted from platinum under the conditions to which the tests were subjected, possessed a velocity distribution in accordance with Maxwell's law.

On the other hand, some preliminary tests made (1) with platinum saturated with hydrogen, (2) with platinum coated with lime, and (3) with the liquid alloy of sodium and potassium, seemed to show the presence of velocity distributions having no very close resemblance to Maxwell's law. These experiments had to be abandoned without the facts being fully ascertained, owing to the pressure of other problems.

In 1914 the subject was attacked by Schottky† who utilised the case of coaxial cylinders presented by a filamentary cathode of circular section and a concentric cylindrical anode. This structure has important practical advantages. The effects of the magnetic and electric fields of the current used to heat the filament were avoided by an interrupted current method due to v. Baeyer. Schottky's experiments were made with carbon and tungsten, and the data were in good agreement with the requirements of Maxwell's law except that the average energy of the emitted electrons was in every case in excess of the value calculated from the temperature of the source. This, however, was estimated from the value of the saturation current in comparison with the emission data given by other authors. In view of the known large effect on the emission of traces of certain possible contaminants this method involves an element of uncertainty; so that one cannot be sure whether the discrepancy exceeds the probable error or not.

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* Richardson, 'Emission of Electricity from Hot Bodies,' p. 146.

† 'Ann. der Physik,' vol. 44, p. 1011 (1914).

The experiments made by Mr. Sih Ling Ting which are described in the sequel were commenced in 1917 at my suggestion in order to try to clear up some of these matters. It was planned first to investigate the behaviour of tungsten using some independent check on the temperature of the filaments and then to investigate the substances whose behaviour had been recorded as abnormal in 1909. Whilst the work is incomplete it is necessary to publish an account of what has been accomplished up to the present, as Mr. Ting is returning to China. I propose to continue it from the present stage with other help.

The following experiments, which I have directed and closely followed throughout, show that whilst Maxwell's law of velocity distribution may be an ideal which is realised in some cases, it is a condition of affairs which is frequently departed from in practice. A very common type of emission appears to be one in which the distribution of velocity is in close agreement with the requirements of Maxwell's law except that the average kinetic energy is about twice that which would correspond to the temperature of the source. Some of the platinum data, however, exhibit velocity distributions which are not at all of the Maxwell type. It may be that the Maxwell type would hold for an ideal flat surface of pure metal and that these variants from it are conditioned by effects of absorbed gas or the like. Some support for such a view may be drawn from the hysteretic effects described by Mr. Ting in Part III, as such effects are generally due to the action of gas films. On the other hand the tubes used by Mr. Ting were undoubtedly freed more thoroughly from gases and the vacua were better in all respects than those I experimented with in 1908. It is hoped that further experiments will indicate more precisely the connection if there is one between the changes in the velocity distribution and the gas actions referred to.

I wish to express my thanks to the Department of Scientific and Industrial Research for a grant which rendered possible the carrying out of the later part of the experiments described in the sequel.

O. W. R.

EXPERIMENTS ON THE VELOCITY DISTRIBUTION OF THE EMITTED ELECTRONS FROM INCANDESCENT FILAMENTS.

Introduction.

Broadly speaking, the method of investigation consists in measuring the electron current from the hot body to a neighbouring electrode against various opposing potential differences. These currents are calculable on the assumption that Maxwell's law of velocity distribution applies to the emitted electrons. In the case of parallel plane electrodes they are then given by equation (1); for a hot wire of circular section and a concentric cylinder they are given by an equation* which, provided the ratio of the two radii is sufficiently great and the opposing voltage is not too small, reduces to

$$i = i_0 \frac{2}{\sqrt{(\pi)}} \left\{ \sqrt{(\alpha \mathrm{V})}\, e^{-\alpha \mathrm{V}} + \int_{\sqrt{(\alpha \mathrm{V})}}^{\infty} e^{-x^2}\, dx \right\}. \tag{2}$$

These conditions as to the ratio of the radii and the magnitude of the voltage were satisfied in the relevant experiments in the sequel. The logarithms of i/i_0 calculated from (1) and (2) are graphed against $\alpha\mathrm{V}$ in fig. 1A. Except near $\alpha\mathrm{V} = 0$, equation (2) gives practically a straight line, whose slope differs about 10 per cent. from that given by (1). By comparing the theoretical with the experimental curves for any particular structure we are enabled to judge if, and to what extent, Maxwell's law is satisfied.

Methods and Principle of the Experiments.

(a) *Preparation of the Tube.*—The forms of the tubes used in the experiments are shown in fig. 1. In the case of the cylindrical field the filament is a short wire held between two thick copper leads. The concentric cylindrical electrode is made of copper wire gauze. For the uniform field the filament is a narrow platinum strip. Two thick platinum foils are used for the two parallel plates. All other metallic parts in this case are also made of platinum, so that the tube can be cleaned by boiling nitric and hydrochloric acids in it. The tube is exhausted in a vacuum furnace, as described by Prof. Richardson in his book ('The Emission of Electricity from Hot Bodies'), by a Gaede mercury pump for about five hours a day for four days. During the exhaustion the temperature of the furnace is kept at about 750° absolute, so that all gases in the wall of the tube and the massive parts of the apparatus may be driven out and pumped off. Liquid air is then placed around the charcoal tube condenser for more than ten hours. While the condenser is still in liquid air the filament is glowed out by a strong electric current for a few minutes, and after about half an hour's interval the tube is then sealed off from the pump. In some cases another charcoal tube condenser is attached to, and exhausted with, the filament tube, and can be immersed in liquid air when observations on thermionic current are being taken.

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* Schottky, *loc. cit.*

(b) *Measurement of Thermionic Current.*—Four different arrangements were used, shown in figs. 2–5. In these diagrams, A is an ammeter for recording the heating current, K or K′ a revolving commutator, G′ a galvanometer in the Wheatstone bridge used for measuring the temperature, G a galvanometer for measuring the thermionic current, B′, P and V a battery, slide wire, and voltmeter, for regulating and measuring the applied potential difference; *k*, *k*′ are keys such as are used in electrostatic measurements, and E denotes an earth connection.

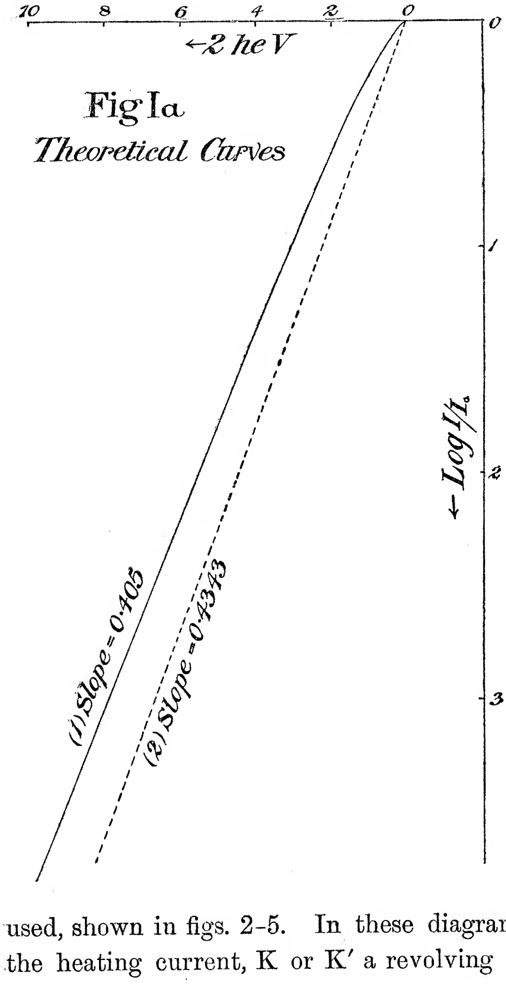
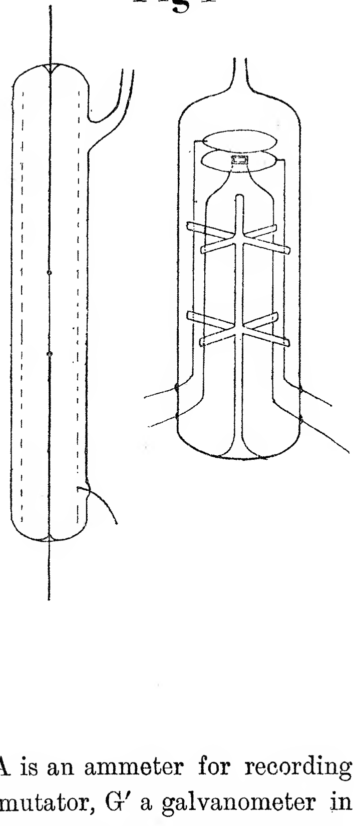


Fig Ia
Theoretical Curves

Fig 1



Method (1), fig. 2, is the arrangement substantially as described by

Schottky. Method (2), fig. 3, shows this method modified to measure small thermionic currents with a sensitive electrometer. The important innovations consist in (*a*) using two separate commutators, K and K′, which, however, are kept in the right phase relation by revolving on the same axis; (*b*) the device J C, J′ C′, which enables the potential of the hot wire to be raised continuously by an amount equal to that of the electrometer, thus maintaining a constant potential difference between the filament and the cold electrode during each measurement. Method (3), fig. 4, has the first feature of Method (2) applied to Method (1). Method(4), fig. 5, is the old arrangement substantially as described by Richardson and Brown.

Fig 2

Method (1)

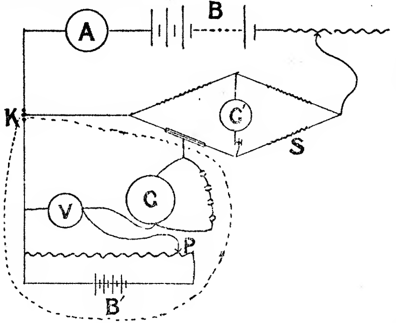


Fig 4

Method (3)

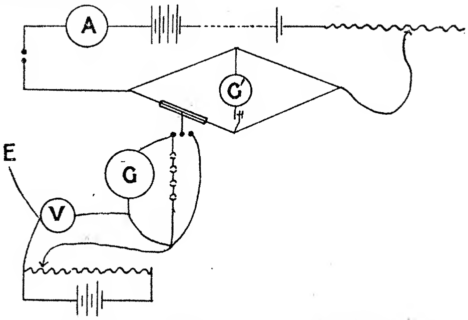
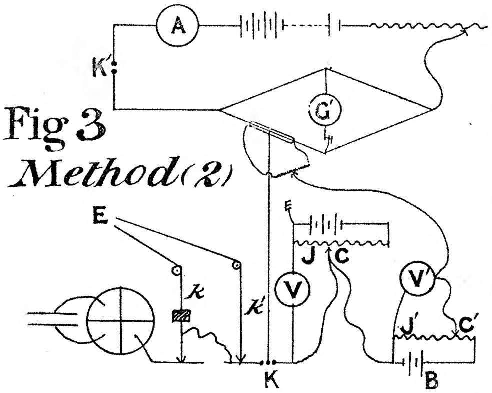


Fig 3

Method (2)



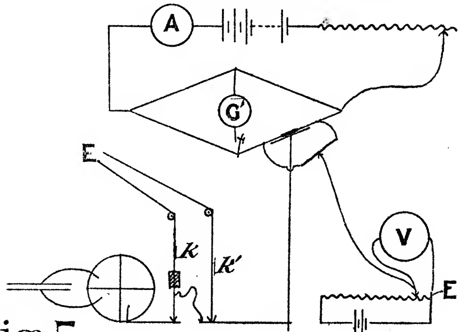


Fig 5

Method (4)

(c) *Estimation of the Temperature.*—Under the condition of a balance of the Wheatstone bridge, the resistance of the filament can be calculated, and hence the temperature can be deduced. For platinum wire and strip, the temperature was taken simply as proportional to the resistance in the actual estimation, and, for tungsten wire, the data given by Langmuir* were made use of.

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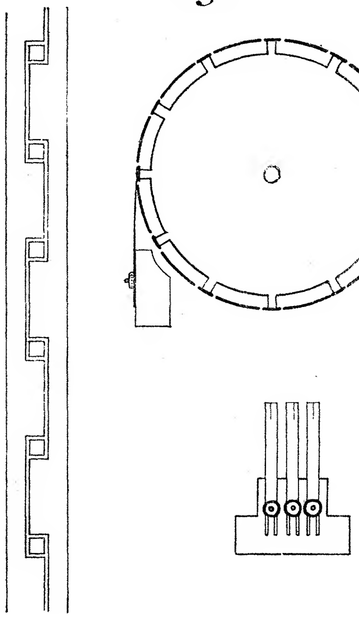
* 'Phil. Mag.,' vol. 7, No. 3 (March, 1916).

From the fact that the filament is heated by current which is interrupted by the commutator (fig. 6), and actually stops for more than half the time, the question arises whether the temperature drops appreciably during the short interval of a break (the commutator makes 150 to 200 breaks per second). Such doubt is, however, removed by the following two tests. A large accelerating potential difference was put on between the filament and the electrode to produce a saturation current. The electrode was connected, not through the commutator, but directly to the galvanometer. The filament was then heated, first by a continuous current, and then an interrupted current to the same temperature as indicated by equal resistance. It was found that the readings of the thermionic currents in the two cases were practically identical. The second test was to compare the temperatures deduced from the saturation current and the resistance. A temperature and saturation current curve was obtained from preliminary observations with the same filament, using continuous heating current. The temperatures were deduced from the corresponding resistances. From this curve, the temperature of the filament, when heated by interrupted current, could be deduced from the saturation current. Account must be taken, of course, of the fact that, when the switch is used, the observed thermionic current is only a fraction of the total emission.

Fig 6



Results of the Experiments.

(a) *Tungsten Wire in Cylindrical Field.*—Three tubes were used in the experiments. With the first tube, five experiments were first made at different temperatures, using the galvanometer for the measurement of current. In some cases two readings of the current for each potential were taken, one when the potential was being increased, and another when it was being decreased. Where there was any difference between the two, which was never very great, the mean value was always taken. When there was only one reading taken, the current was allowed to become steady. The filament was then strongly heated by a current for a few hours, and two more observations were made. The result of all the experiments shows that the I–V curves are all logarithmic in character, but the slope of the log I–V curves is in each case only about half the value calculated from the temperature in accordance with Maxwell's law, as may be seen from the following Table :—

Table I.—First Tube (thin filament). Method (1).

Diameter of filament 0·00549 cm.; length of filament 6·83 cm.; diameter of cylinder 2·2 cm.; length of cylinder 12·5 cm.

Temperature.	Approximate saturated current.	Slope of log I–V Curve.		Ratio S/S′.
		S (experimental).	S′ (theoretical).	
K.	mm.			
1455	101	1·63	3·17	0·51
1475	161·5	1·60	3·12	0·51
1500	241·5	1·60	3·07	0·52
1528	464	1·60	3·02	0·53
1574	1015	1·55	2·92	0·53
		(After Heating.)		
1574	224	1·73	2·92	0·59
1626	487	1·69	2·85	0·59

In the above Table the current is expressed in terms of the galvanometer readings (1 mm. 3·46, 10^{-8} ampères). The current was greatly reduced after the strong heating. But the logarithmic nature of the curve was found unaltered, though the value of the slope seemed thereby slightly increased. The general character of the curves can be seen from figs. 7*a* and 7*b*, where the result of the first five experiments are represented. The curve shown by the dotted line is the theoretical curve for temperature 1455 K.

The second tube was made exactly like the first. The filament was of the same wire. Altogether, seven experiments were made. The first four were made with the galvanometer at temperatures ranging from 1400 K to 1700 K. Method (3) was used. The last three were made with the electrometer at lower temperatures, using Method (2). The temperatures of the filament in the first four experiments were estimated also from the saturation current, and were found in good agreement with the values calculated from the resistance. As in the case of the first tube, all the curves obtained are logarithmic, and the slope is only about half of the theoretical value.

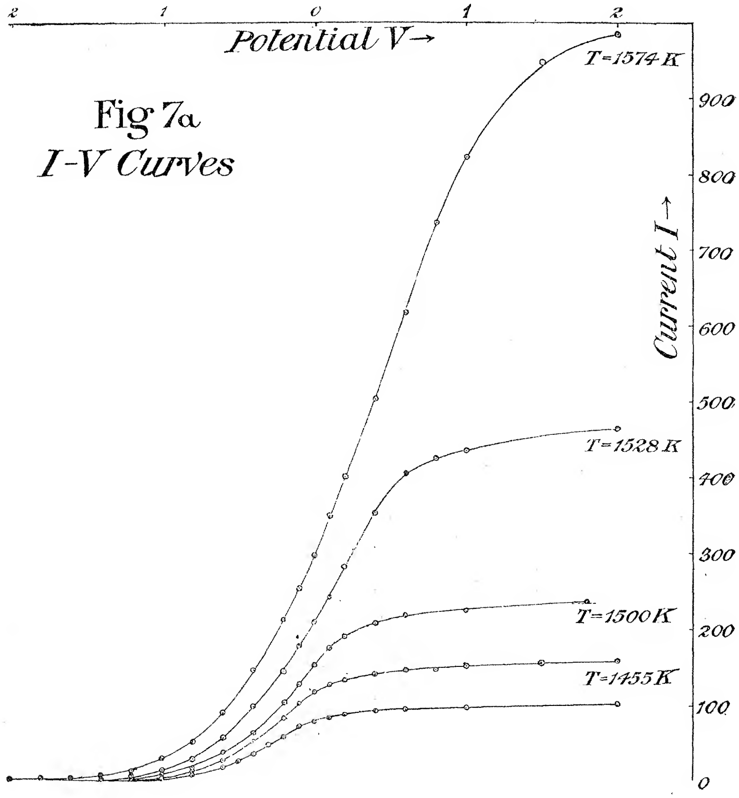


Table II.—Second Tube (same wire). Methods (2) and (3).

Temperature.		Slope.		S/S′.
From resistance.	From saturated current.	S (experimental).	S′ (theoretical).	
K.				
1700	1703	1·2	2·71	0·44
1600	1600	1·3	2·88	0·45
1500	1490	1·45	3·07	0·47
1400	1360	1·8	3·29	0·55
1100	—	2·3	4·18	0·55
1080	—	2·6	4·26	0·61
1060	—	2·8	4·34	0·65

The above Table shows clearly that the slope S increases with decrease of temperature, and the ratio S/S′ is not far from half in all cases. The curves for the first four experiments are similar to those shown in fig. 7; those for the last three experiments are shown in fig. 8. One difference between these curves and all the others should be noted, namely, the current attained saturation when there was still a resisting potential difference between the filament and the electrode of about 0·7 volt.

The same result was found with the third tube. The filament was a thicker wire. Method (2), with the electrometer, was used. The value of the ratio S/S′ obtained was 0·49 for temperature 1030 K.

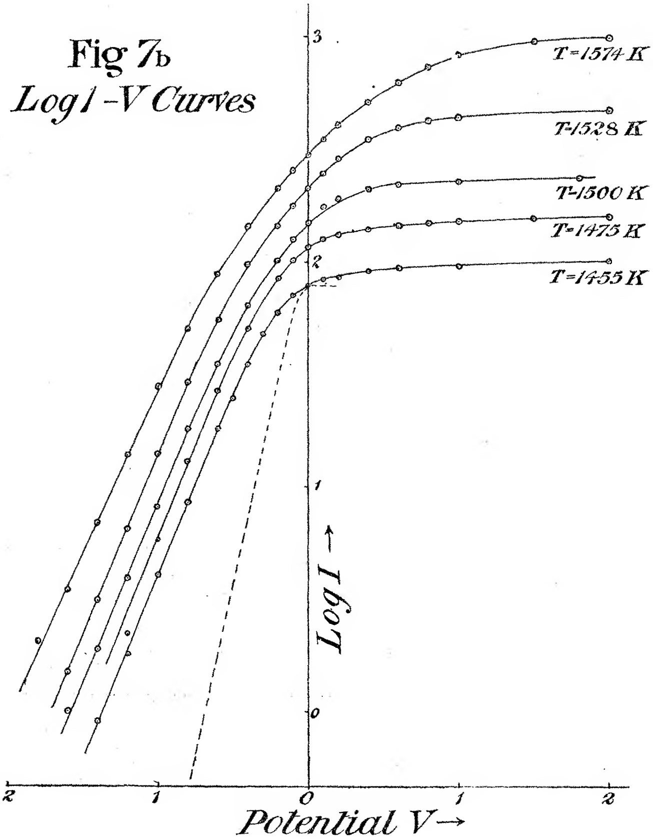


Fig 7b
Log I -V Curves

(b) *Platinum Wire in Cylindrical Field.*—In this case an improved form of the tube was used, to minimise the error due to the escape of the electrons from the open ends of the electrode and the falling off of the temperature at the ends of the filament. The filament used was a long platinum wire, and the electrode consisted of three separate parts, of which only the middle was connected to the current-measuring instrument; the other two simply served as "guard-rings." The result is shown in the following Table and in fig. 8*a*.

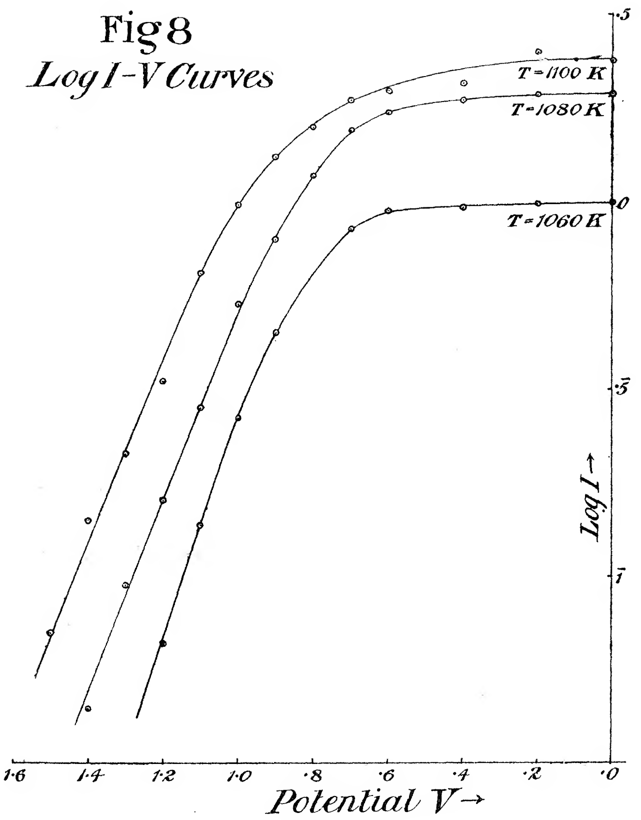


Fig 8

Log I-V Curves

Table III.—Tube with Long Filament and Short Electrode. Method (2).

Temperature.	Slope S (experimental.	Slope S′ (theoretical).	Ratio S/S′.
890 (1)	2·3	5·2	0·44
910 (3)	2·9	5·1	0·57
940 (2)	2·9	4·9	0·59
975 (5)	2·3	4·7	0·49
1000 (4)	2·46	4·6	0·53
1050 (6)	—	4·4	—

The values of the temperature in the Table are only approximate. The curve for the last experiment is not quite straight, owing to the high temperature and the great current. The value of S and the ratio S/S′ do not change regularly with the temperature, as in the case of the tungsten filaments. This is probably due to the fact that the experiments were not made in the order of the temperature, but in the order as indicated by the numbers in brackets, and were not made one immediately after another.

From all the experiments described above, both with tungsten and platinum filaments in a cylindrical field, we can draw the conclusion that, practically in every case, we have—

(1) A logarithmic curve if the values of the thermionic current are plotted against the corresponding values of the potential difference between the filament and the electrode; and

(2) The slope of the curve with the logarithms of the values of the current against the values of the potential difference is equal to only about half of the value as required on the assumption that the velocities of the emitted electrons are distributed in accordance with Maxwell's law, or in other words, the actual velocity distribution corresponds to a temperature about twice as high as the actual temperature estimated from the resistance of the filament.

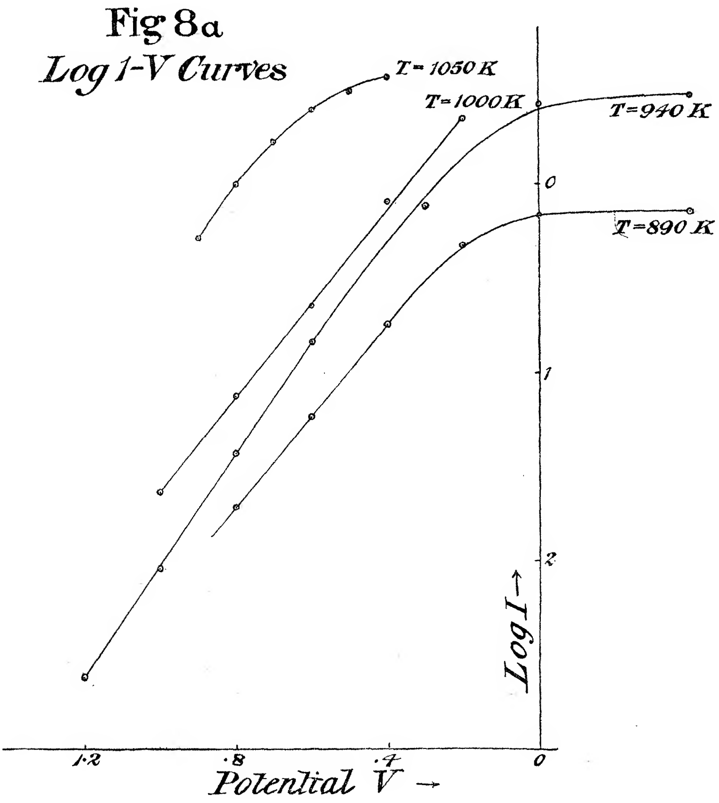


Fig 8a

Log I-V Curves

(c) *Platinum Strip in Uniform Field.*—Before the tube (fig. 1) was joined to the pump it was boiled with nitric and hydrochloric acid, each for about two hours, and then cleaned with distilled water. In the first series of experiments the tube was left on the pump which was working continuously when observations on the thermionic current were made. No liquid air was applied to the charcoal tube condenser. The curves of the first few experiments were varying owing to the positive current present which, at the beginning, was as great as the negative. By continuously heating the filament with a large electric force to drive it off it slowly died down. When it disappeared entirely the curve assumed the characteristic logarithmic form. When the pressure in the tube was higher than 1/100 of 1 mm. of Hg the curve was no longer consistent but when the pressure was fairly low and no positive current was present the I–V curve was logarithmic. The strength of the current, however, was found to decrease by heating. The results of four experiments under such conditions are given below.

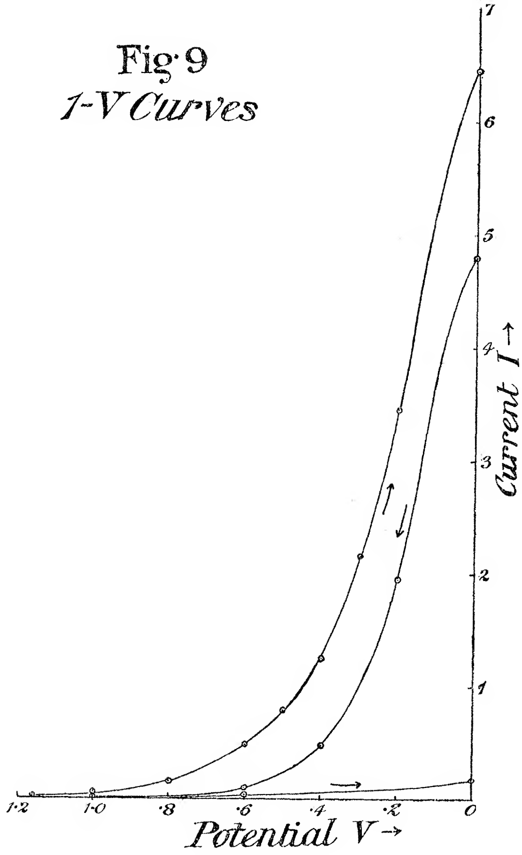
Table IV.—First Tube with Platinum Strip. Method (4).

Diameter of platinum plate 2·5 cm. (about); distance between plates 0·5 cm. (about); dimension of the rectangular hole = 5 × 2 sq. mm.

Temperature.	Slope S (experimental).	Slope S′ (theoretical).	Ratio S/S′.
1466	1·7	3·46	0·49
1460	1·89	3·47	0·53
1450	2·1	3·5	0·60
1500	1·85	3·38	0·55

The same tube together with the attached charcoal tube condenser was then put in the vacuum furnace, and heated and exhausted in the manner described before. When the tube was finally sealed off from the pump the charcoal tube condenser was immersed in liquid air during all the experiments. In the first experiment at the very beginning no positive current was found. The curve was logarithmic and gave a much larger value for the slope. In fact the value was not far from that required by Maxwell's law. But immediately after the first experiment the thermionic current was found to be decreasing. At the same time the curve lost its logarithmic character. The decreasing of the current was more rapid at first and became slower and slower. The shape of the curve, however, remained more or less unaltered. The removal of the liquid air from the condenser did not make any difference either in the strength of the current or the shape of the curve. The filament finally burnt off after many hours' continuous heating.

The second tube was made exactly like the first with the old electrodes and a new strip. It was treated in the same way and the experiments were carried out under the same conditions. The result obtained entirely agreed with that of the first tube; namely, the thermionic current decreased first rapidly and then slowly, the curve changed from a logarithmic character to a different one. How the current dropped down in the first half-hour may be seen from the curves in fig. 9 where the three observations were made one after another at the same temperature with only a few minutes' interval. The final shape of the curve, when the current had become more or less steady, is shown in fig. 10. The lower curve was taken six hours after the top one, the temperature being the same.



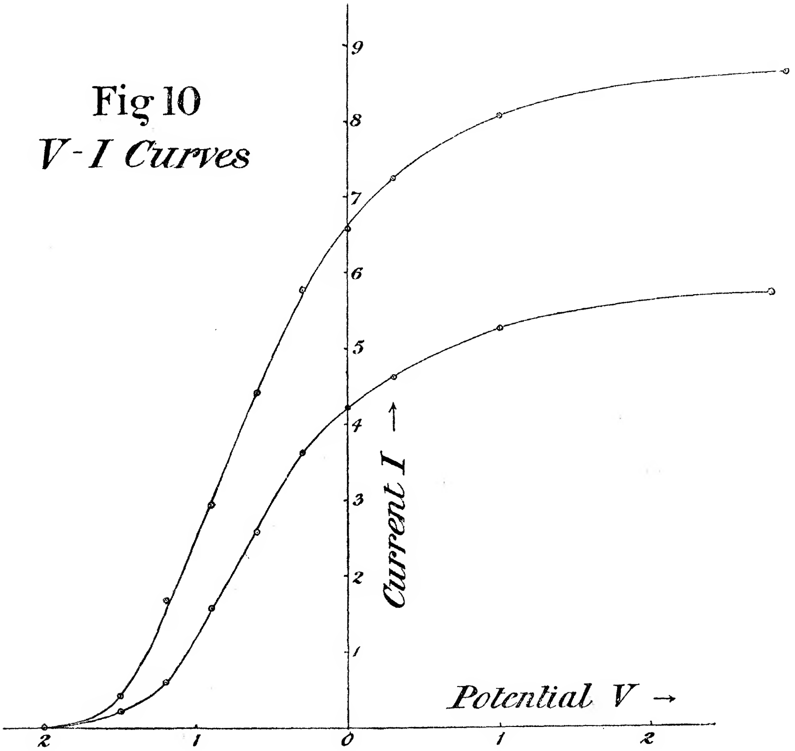
The result of the above experiments with platinum strips in a uniform field points to the conclusion that in tubes at pressure of the order of 10^{-3} mm. Hg the electrons emitted by a platinum strip have the same property in regard to velocity distribution as those emitted by platinum and tungsten wires. But this property disappears with the simultaneous decrease of the thermionic current in tubes which have been baked and exhausted in the vacuum furnace, and which have an attached charcoal tube condenser immersed in liquid air when the filament is heated during the experiment.

It may be mentioned in this connection that the thermionic current in the experiments with tungsten wires remained very constant for hours and no positive current was ever detected.

(d) *Platinum Filament Coated with Chemical Compounds.*—The tube used was of the type of a long wire surrounded by a short cylindrical electrode with "guard-rings." Make-and-break switches were used. The first tube was coated with barium and strontium oxides. In the experiment with this filament the thermionic current was found measurable by a sensitive galvanometer when the filament was only very dull red hot. When the electrometer was used the filament was hardly visible in the dark. The most striking feature is, however, the inertness of the electrons emitted. To get a measurable current some driving force is generally required, except at very high temperatures, and even then the current does not increase appreciably until the potential difference is increased to about 1 volt. Generally speaking the current starts when more than 1 volt potential is put on, but at about 600 K. in one of the experiments a potential of 2 was found necessary. The other important feature is the difficulty of saturating the current. The current generally increases with the driving potential up to from 100 to

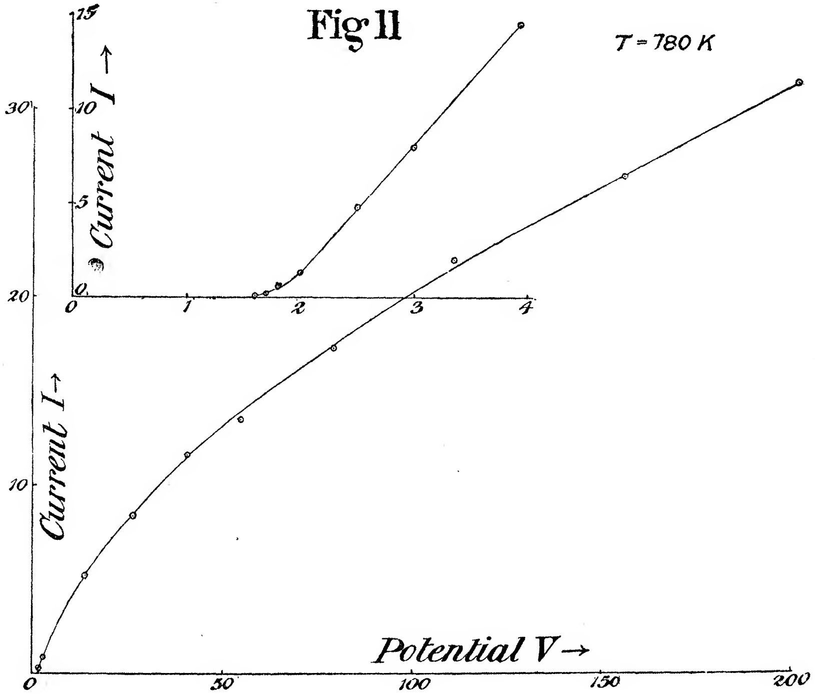
Fig 10

V-I Curves



200 volts without showing any tendency towards saturation. The results of one experiment are shown in fig. 11. The top curve shows the beginning part of the lower one on a larger scale. All the other curves are similar to this. Similar results were obtained from a wire coated with lime, obtained by evaporating drops of pure $Ca(NO_3)_2$ solution on the filament.

Fig 11



Observations on Hysteretic Effects in Thermionic Electron Currents.

During some experiments on the velocity distribution of the electrons emitted from tungsten wire, in which the thermionic current was measured for various potential differences between the emitting filament and the surrounding electrode, a curious effect was observed in regard to changes of the current with time. It was found that so long as the potential difference was small or was so directed as to resist the emitted electrons the thermionic current had a definite value for each potential difference; but when a large accelerating potential difference was put on, the current changed with time and only settled down to a steady value after a considerable time. The initial value of the current often differed considerably from the steady value, and was greater or smaller than the steady value according to whether the previous potential difference was greater or smaller; or, to be more exact, according to whether the current for the previous potential difference was greater or smaller. This distinction must be made because it was found that greater potential difference did not necessarily produce greater current; but, on the contrary, the current showed a maximum at certain points, beyond which it decreased.

The experiments were made with long glass tubes, each of which had a short tungsten filament, of about 2 to 3 cm. length, and a concentric cylindrical electrode, of about 10 cm. length and 2·5 cm. diameter, made of copper wire gauze. The tube was exhausted and heated in a vacuum furnace for about

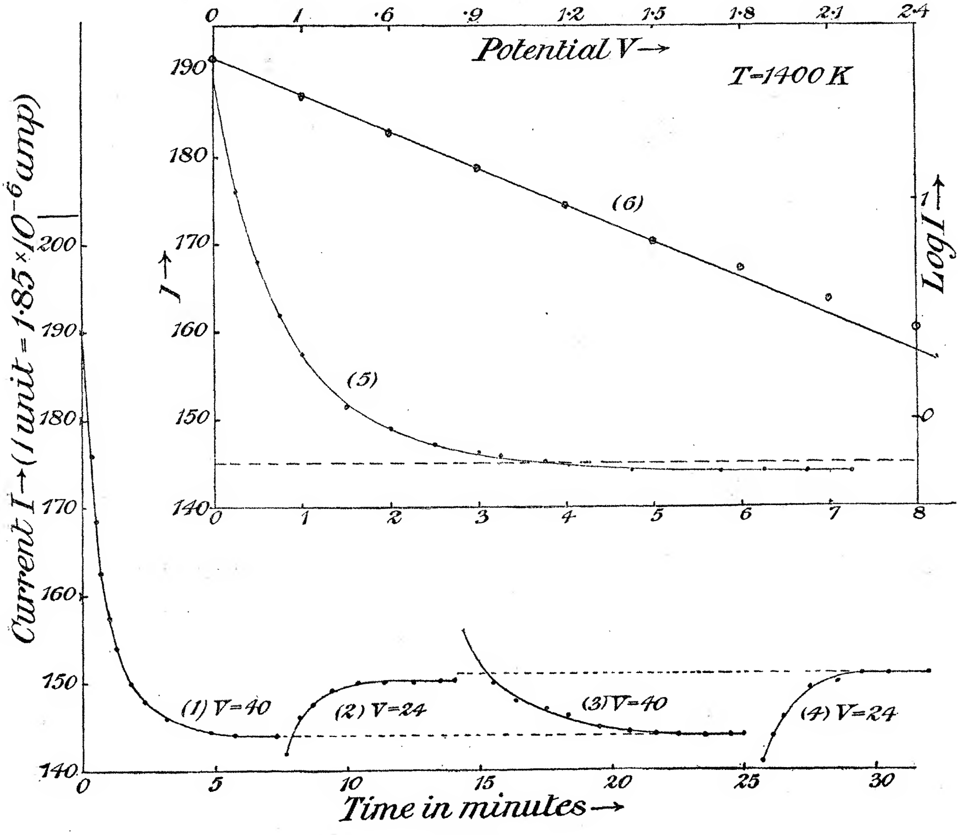


Fig. 12.

twenty hours. Before it was sealed off from the pump the charcoal tube condenser in connection with the pump was put in liquid air for a long time and the filament was glowed out by a strong current. To take observations of the thermionic current, the filament, which formed one arm of a Wheatstone bridge, was heated by an electric current. One end of the filament was earthed and the electrode was then charged to different potentials. The current was measured by a sensitive galvanometer. In the first experiment a potential of 40 volts was put on the electrode when the temperature of the filament became constant. The current started with a certain initial value, but decreased, first rapidly then slowly, and finally settled down to a steady value after about seven minutes. The potential was then changed to 24 volts. The current dropped a little at the beginning, but rose to a greater value than for 40 volts, when it became steady again. In order to make sure that the increase of the current was not due to a change of the emission, the potential was changed back again to 40 volts. At once the current increased, but soon fell down to its former steady value for that potential. Only the initial value this time was much less than for the first time. On changing the potential once more to 24 volts, the same phenomenon repeated itself. The result of the experiment is shown in fig. 12, where the curves are plotted with current against time. From these curves we see clearly that (1) there was a definite steady value of the current for

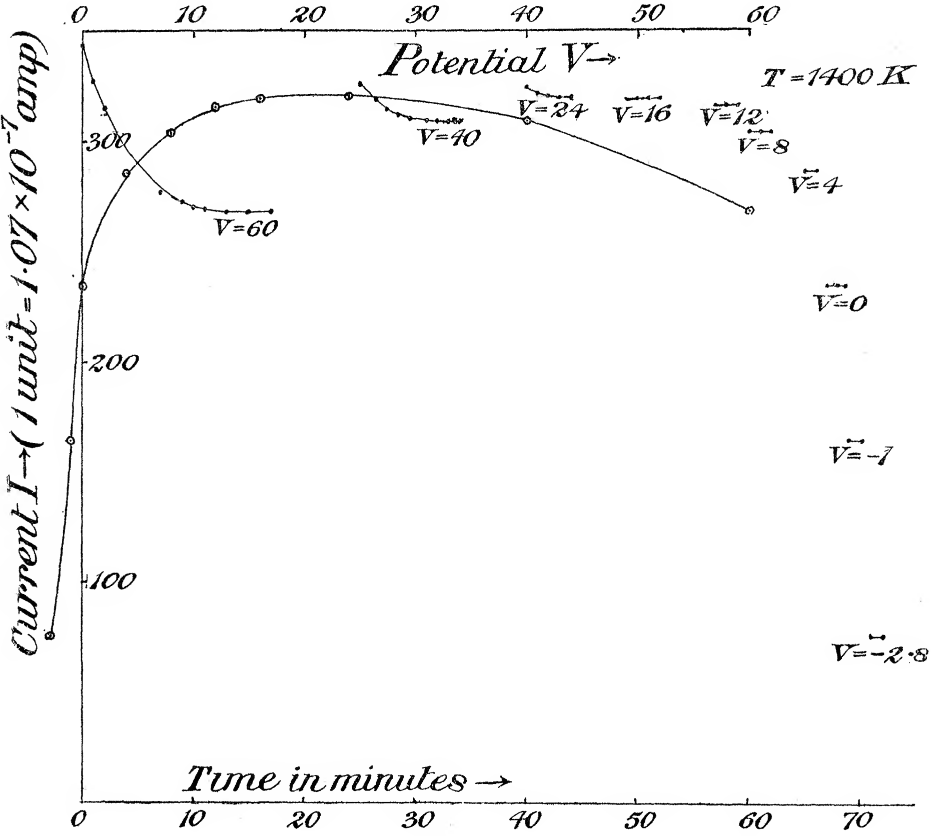


Fig. 13.

each potential, and the value for 24 volts was decisively greater than that for 40 volts; (2) the initial value of the current was influenced by the previous potential in the way indicated above. Curve 5 in the same figure is simply curve 1 on a larger scale, and curve 6 is plotted with the logarithm of the excess of current above the dotted line against time. The latter as shown is nearly a straight line.

The object of the second experiment, which was made with the same tube, was to find the steady value of the current at a number of potentials. To eliminate the effect of the previous potential, each potential was taken off for a few minutes before the next was put on. The result (fig. 13) shows the disappearance of the initial drop of the current, but the existence of a maximum value was made very clear.

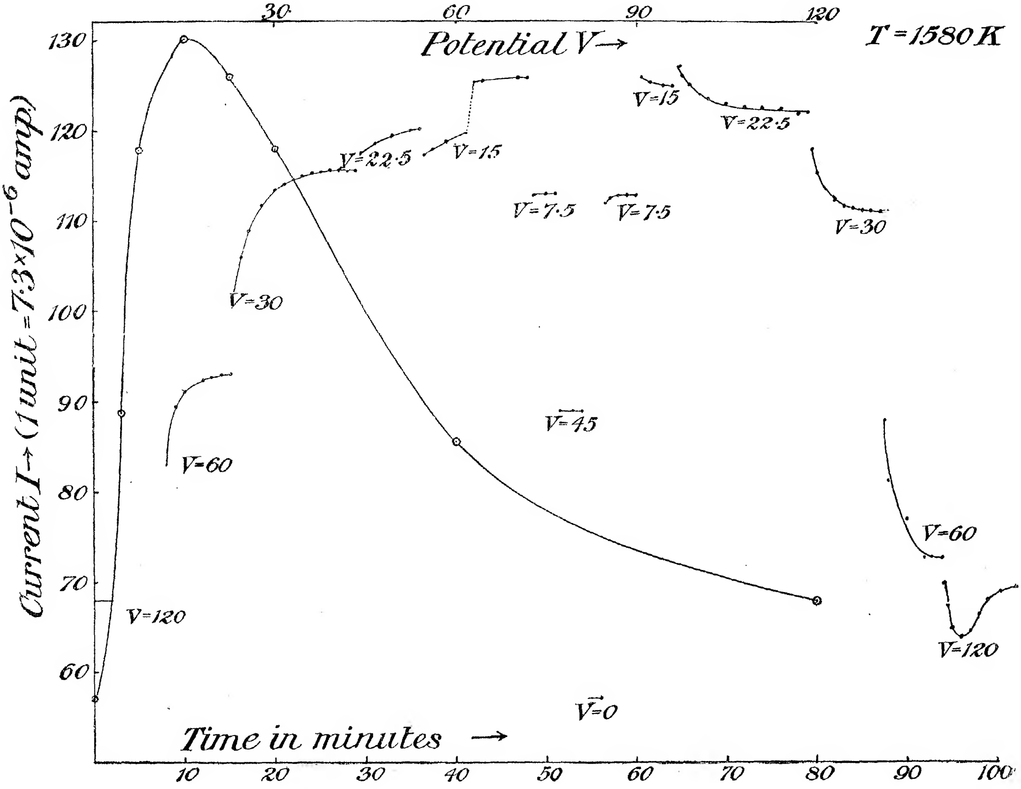


Fig. 14.

The same result was obtained with the second filament, which was thicker and perhaps less pure than the first. Although the condition of the vacuum was improved by immersing in liquid air a charcoal tube condenser, which was attached to the filament tube and had been exhausted together with it, the effect observed was even more striking, as is shown in fig. 14. Two points in the figure deserve special notice. Firstly, the change of the current was so rapid that, in most cases, the initial drop or rising could not be observed. Secondly, there was a shifting of the steady value of the current for the larger potentials. This might be due to the change of the emission during the long interval between the two readings of the current.

The above experiments were made at temperatures of about 1600° K. or more. At such high temperatures the hysteretic effect was more noticeable and persistent. At lower temperatures the existence of the maximum was found to disappear, and the current to decrease after the filament had been strongly heated for some time with a large positive potential on the electrode.

The last series of experiments was concerned with the observance of the occurrence of the maximum current and its corresponding potential at different temperatures. A third tube was used with a filament of the same kind as used in the first tube. The maximum of the current was not so marked as in the previous experiments, but was quite distinct. The potential at which the maximum occurred increases with temperature. At the lowest temperature no maximum was found. The result is shown in the following Table:—

Temperature.	Potential giving maximum current.
1960° K.	60 volts
1720	45
1630	32
1590	28
1480	None.

Taking the maximum value for the current, the relation between the current and the temperature was found to satisfy Prof. Richardson's formula closely,

$$i = \mathrm{AT}^{\frac{1}{2}} e^{-b/\mathrm{T}},$$

where T is the absolute temperature, A and b are constants, and i is current per unit area of the emitting surface.

Phenomena of the same kind as described above have been noticed before by several investigators on thermionic emission. They were observed first by Prof. Richardson* in his experiments on the emission of positive ions from hot platinum in different gases, by Prof. Richardson and Sheard,† and later by Lester,‡ in experiments on both positive and negative emission of hot filaments in vacuum. Langmuir[*] also found the existence of a maximum current in his experiments on the emission of electrons by tungsten wire in nitrogen, and put forward a theory for its explanation. According to this theory, ionised nitrogen acts upon the hot tungsten, and forms a compound which, though unstable, may remain on the surface of the wire for a short time and while it is on the surface, it is supposed to hinder the emission of the filament. This theory can be extended to account for the effect due to previous potentials on the thermionic current by supposing that the compound on the surface of the filament requires some time to adjust itself to suit new conditions for equilibrium. But, on the other hand, the theory is limited to tungsten in nitrogen, while the same effects have been found to happen with tungsten in an apparently good vacuum, with platinum in a vacuum and in oxygen, in positive as well as in negative emission. The explanation must be of a more general character. But under precisely what conditions the filaments produce such peculiar effects, whether, for instance, it is due to a film formed by chemical action on the filament or otherwise, is not quite clear at present.

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* 'Phil. Trans.,' A, vol. 207, p. 10 (1906).

† 'Phil. Mag.,' vol. 31, p. 554 (1916).

‡ 'Phil. Mag.,' vol. 31, p. 554 (1916).

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[*] 'Phys. Rev.,' vol. 2, p. 467 (1913).